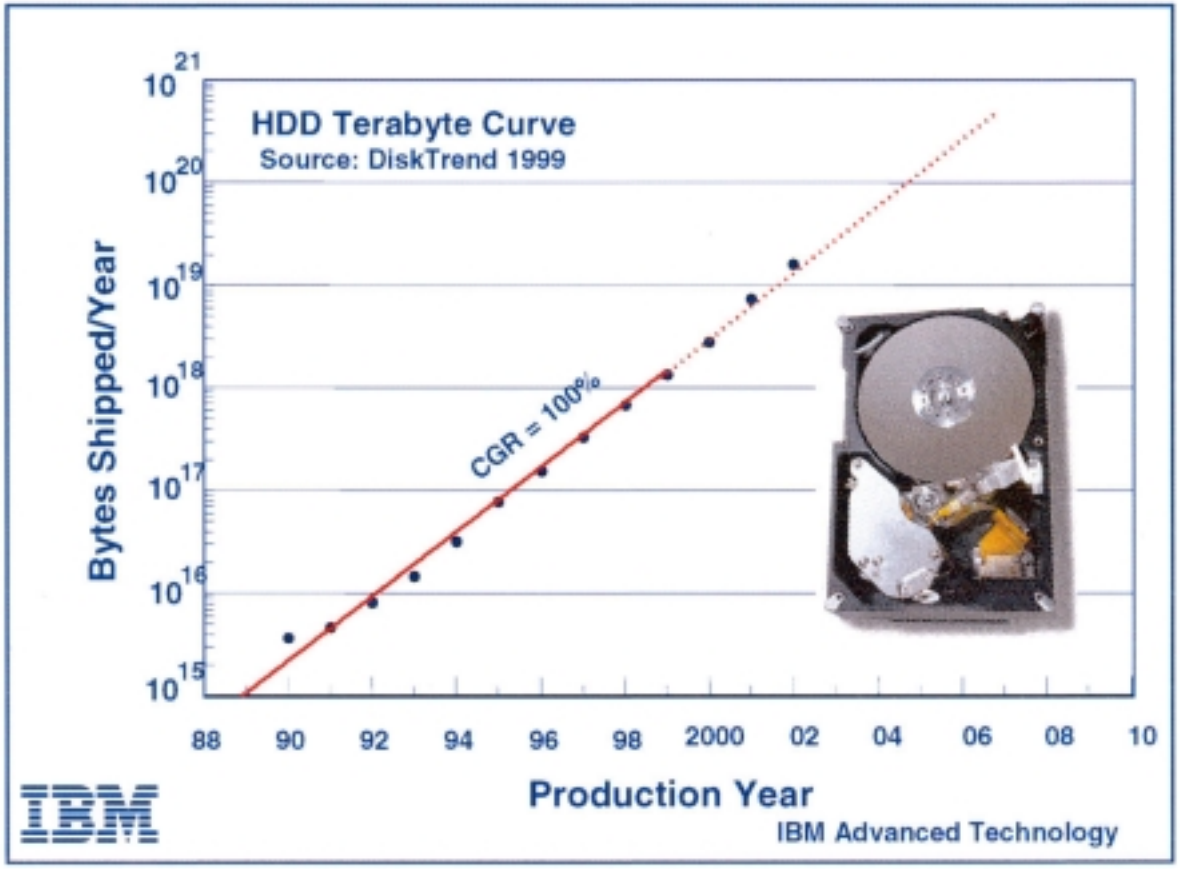
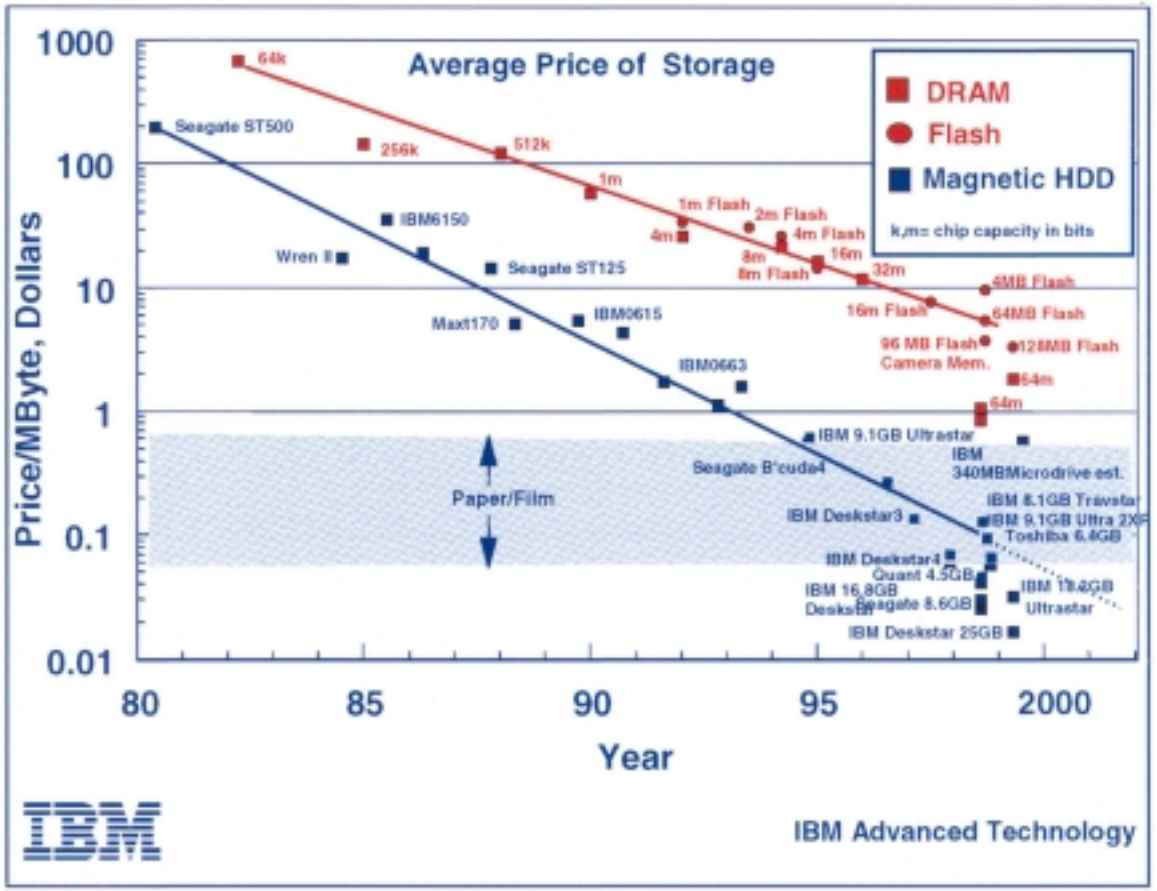
Advanced Storage Technology-
Trends in Magnetic Hard Disk Drives

Ed Grochowski
Program Manager of Storage Devices
IBM Almaden Research Center
San Jose, CA 95120-6099

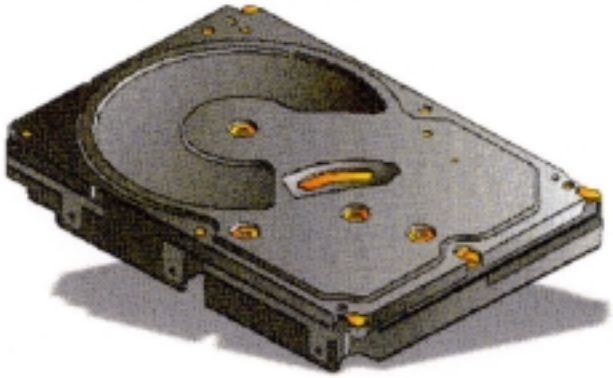
Eighth NASA Goddard Space Flight Center Conference
Mass Storage Systems and Technologies
17Th IEEE Symposium Mass Storage Systems
University of Maryland, College Park, Maryland
March 27-30, 2000

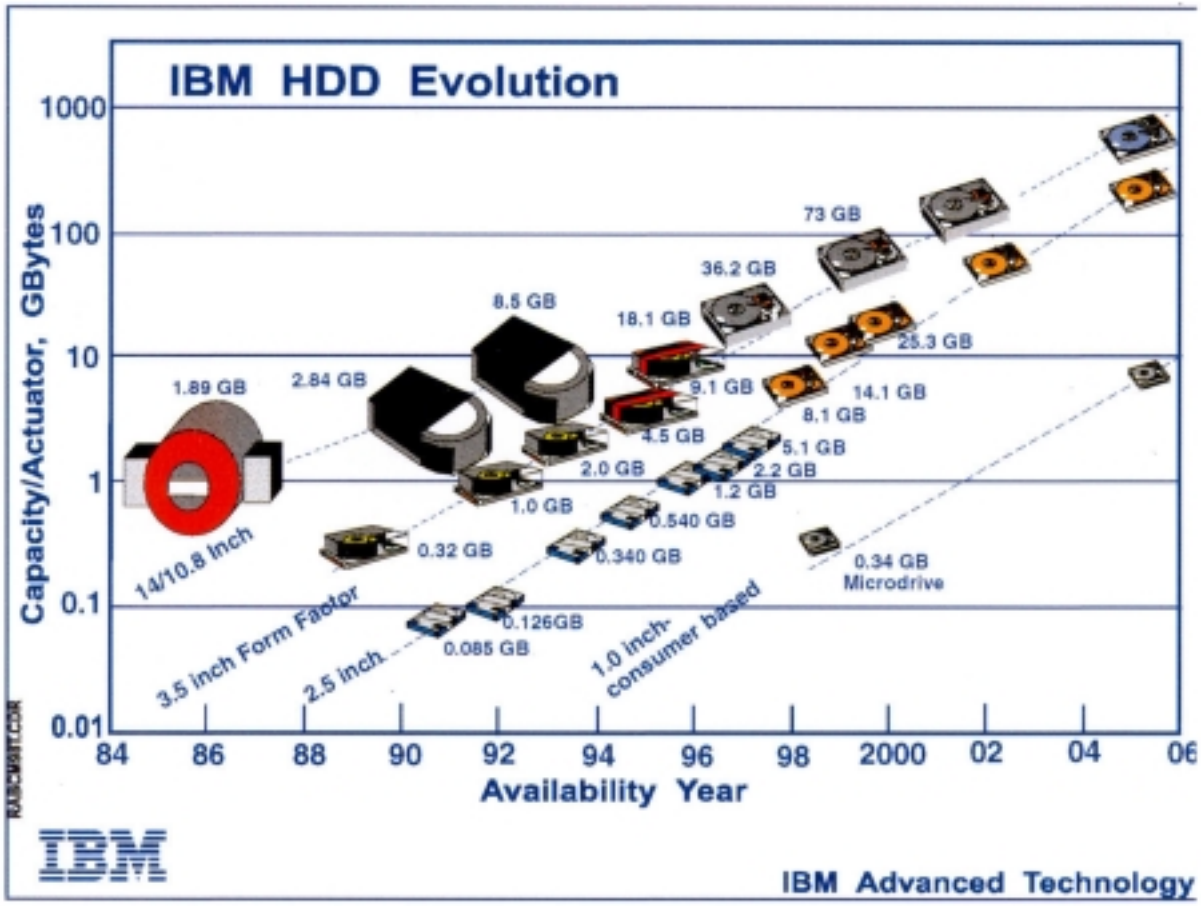
NASA2000A.ppt


HDD Terabyte Curve
Source: DiskTrend 1999
Bytes Shipped/Year
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
CGR = 100%
88
90
92
94
96
98
2000
02
04
06
08
10
Production Year
IBM
IBM Advanced Technology


Average Price of Storage
DRAM
Flash
Magnetic HDD
k,m= chip capacity in bits
Price/MByte, Dollars
1000
100
10
1
0.1
0.01
80
85
90
95
2000
Year
64k
256k
512k
1m
1m Flash
2m Flash
4m
4m Flash
8m
8m Flash
16m
32m
16m Flash
4MB Flash
64MB Flash
96 MB Flash
Camera Mem.
128MB Flash
64m
64m
Seagate ST500
IBM6150
Wren II
Seagate ST125
Maxt170
IBM0615
IBM0663
IBM 9.1GB Ultrastar
Seagate B'cuda4
IBM
340MBMicrodrive est.
IBM 8.1GB Travsta
IBM 9.1GB Ultra 2XP
Toshiba 6.4GB
IBM Deskstar3
IBM Deskstar4
Quant 4.5GB
IBM 16.8GB
Seagate 8.6GB
IBM 11.8GB
Ultrastar
IBM Deskstar 25GB
Paper/Film
IBM
IBM Advanced Technology

Assembling a Disk Drive



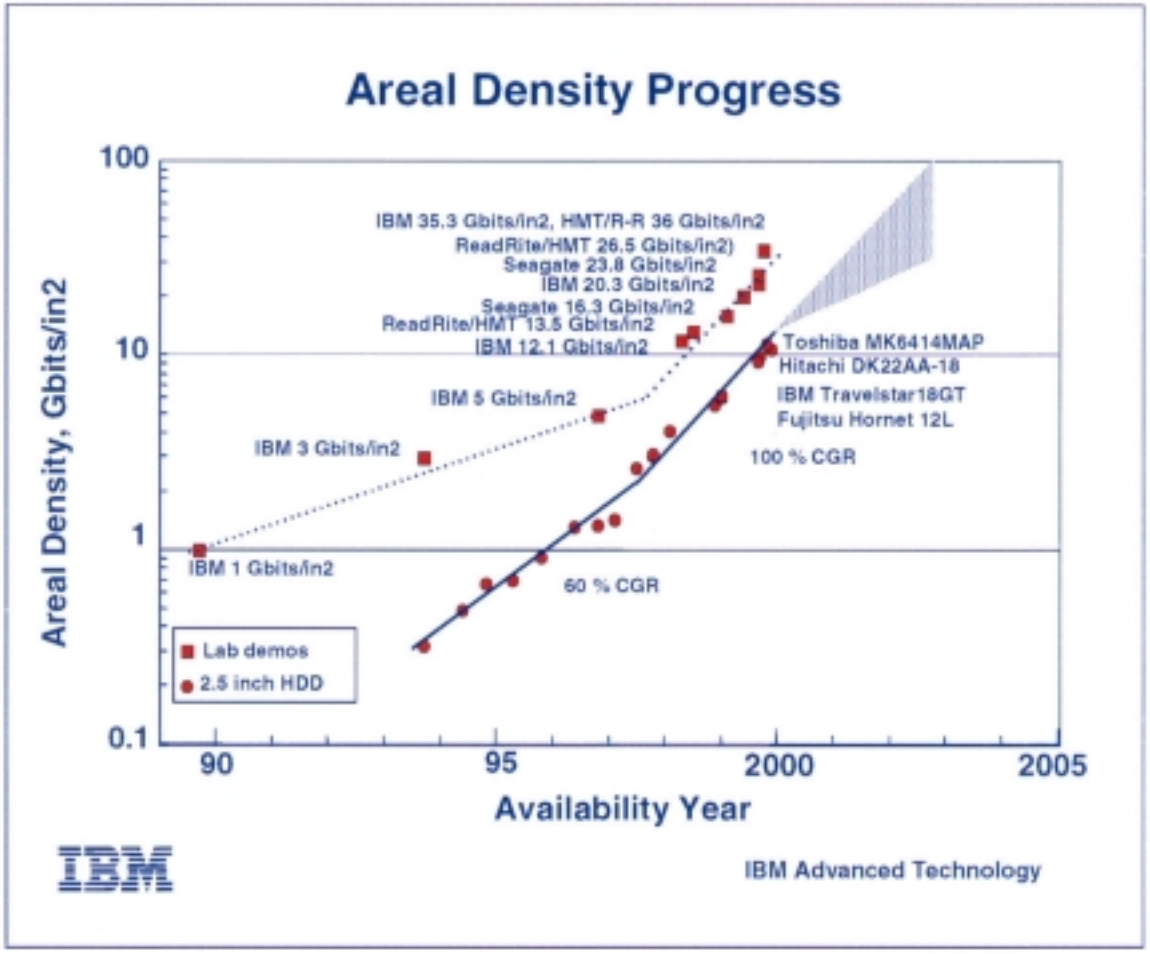

IBM HDD Evolution
Capacity/Actuator, GBytes
1000
100
10
1
0.1
0.01
84
86
88
90
92
94
96
98
2000
02
04
06
Availability Year
1.89 GB
2.84 GB
8.5 GB
18.1 GB
36.2 GB
73 GB
25.3 GB
9.1 GB
14.1 GB
8.1 GB
4.5 GB
5.1 GB
2.0 GB
2.2 GB
1.2 GB
1.0 GB
0.540 GB
0.32 GB
0.340 GB
0.34 GB
Microdrive
0.126GB
0.085 GB
14/10.8 Inch
3.5 inch Form Factor
2.5 inch
1.0 inch-
consumer based
IBM
IBM Advanced Technology

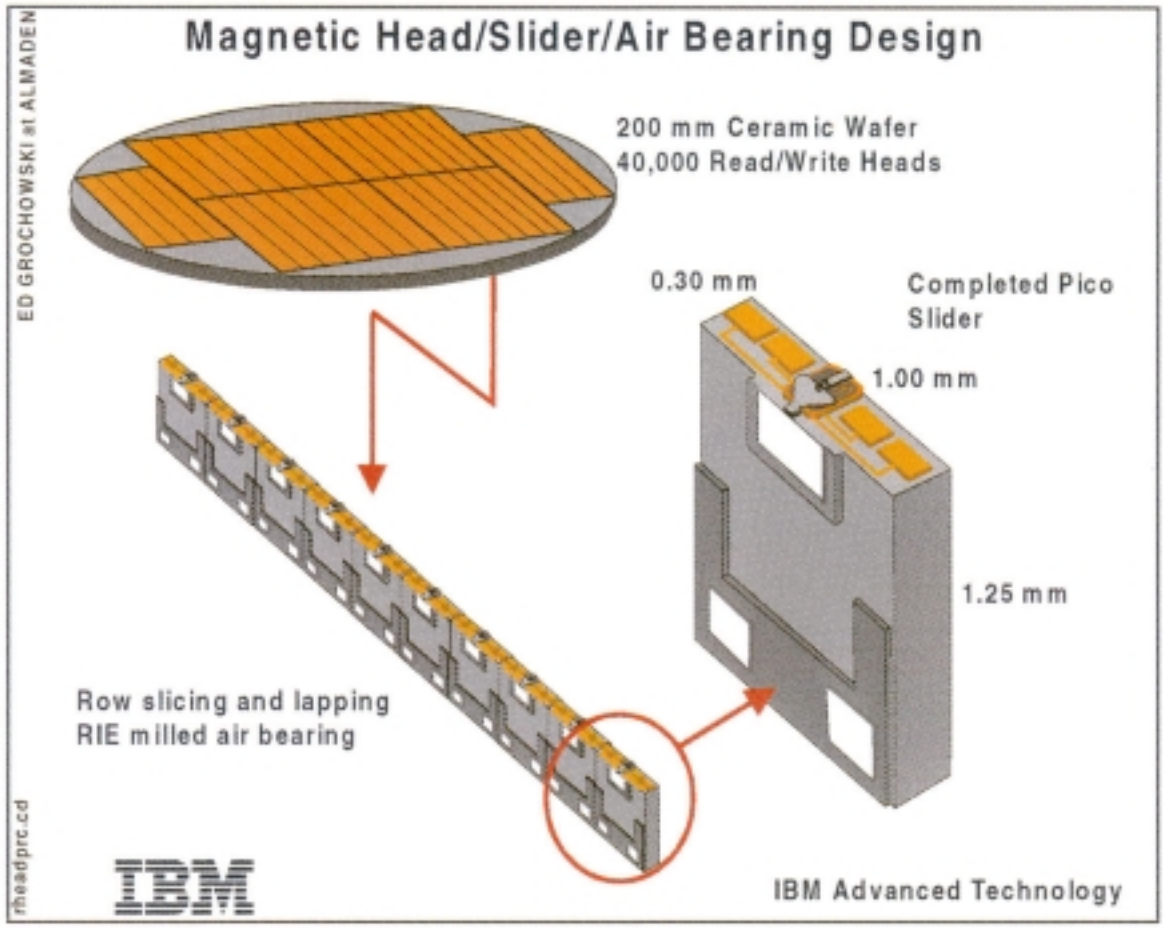
HDD Design Projections

	1999	2000	2002	2004	2006
Server 3.5 Inch HDD 41.3 mm high	36GB 10000 RPM 5.4ms Tseek	73 GB 10000 RPM 4.9ms Tseek	73GB 15000 RPM 4.5ms Tseek		
Entry-Server 3.5 Inch HDD 25.4 mm high	37 GB 7200 RPM 8.5 ms Tseek	50 GB 7200 RPM 8.5 ms Tseek	72 GB 10000 RPM 7.0 ms Tseek	150 GB 15000 RPM 4.0 ms Tseek	300 GB 15000 RPM 3.0 ms Tseek
Mobile 2.5 Inch HDD 9.5/12.5/17 mm high	25 GB 5400 RPM 12 ms Tseek	35 GB 5400 RPM 10 ms Tseek	50 GB 5400 RPM 9.0 ms Tseek	100 GB 7200 RPM 7.0ms Tseek	150 GB 10000 RPM 5.0ms Tseek
Consumer 1.0 Inch HDD 5.0 mm high	0.34 GB 4500 RPM 15 ms Tseek	0.6 GB 4500 RPM 15 ms Tseek	1.3 GB 4500 RPM 15 ms Tseek	3.2 GB 5400 RPM 12 ms Tseek	6.0 GB 5400 RPM 10 ms Tseek

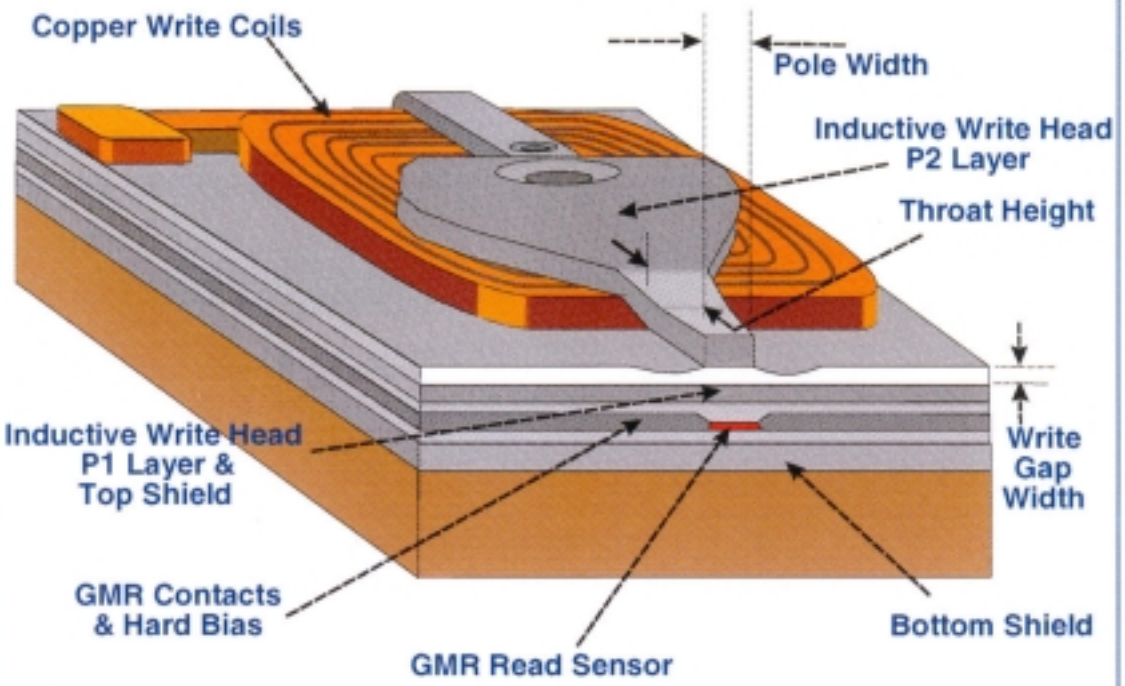
IBM Microdrive-A New Disk Drive Technology

- 340 MB CF Type II format, removable HDD, 43 x 36 x 5 mm
- GMR Heads, 1 inch diameter glass disk, ramp load/unload
- Weight 17 g
- Handheld market: digital cameras, cellular phones, palmtop computers
- High capacity alternative to flash cards
- 15 ms average seek time, 49 mbits/sec. media transfer rate


Areal Density Progress
Areal Density, Gbits/in2
100
10
1
0.1
90
95
2000
2005
Availability Year
IBM 35.3 Gbits/in2, HMT/R-R 36 Gbits/in2
ReadRite/HMT 26.5 Gbits/in2)
Seagate 23.8 Gbits/in2
IBM 20.3 Gbits/in2
Seagate 16.3 Gbits/in2
ReadRite/HMT 13.5 Gbits/in2
IBM 12.1 Gbits/in2
IBM 5 Gbits/in2
IBM 3 Gbits/in2
IBM 1 Gbits/in2
Toshiba MK6414MAP
Hitachi DK22AA-18
IBM Travelstar18GT
Fujitsu Hornet 12L
100 % CGR
60 % CGR
Lab demos
2.5 inch HDD
IBM
IBM Advanced Technology


Magnetic Head/Slider/Air Bearing Design
ED GROCHOWSKI at ALMADEN
200 mm Ceramic Wafer
40,000 Read/Write Heads
0.30 mm
Completed Pico
Slider
1.00 mm
1.25 mm
Row slicing and lapping
RIE milled air bearing
rheadprc.cd
IBM
IBM Advanced Technology

Inductive Write/GMR Read Head Structure



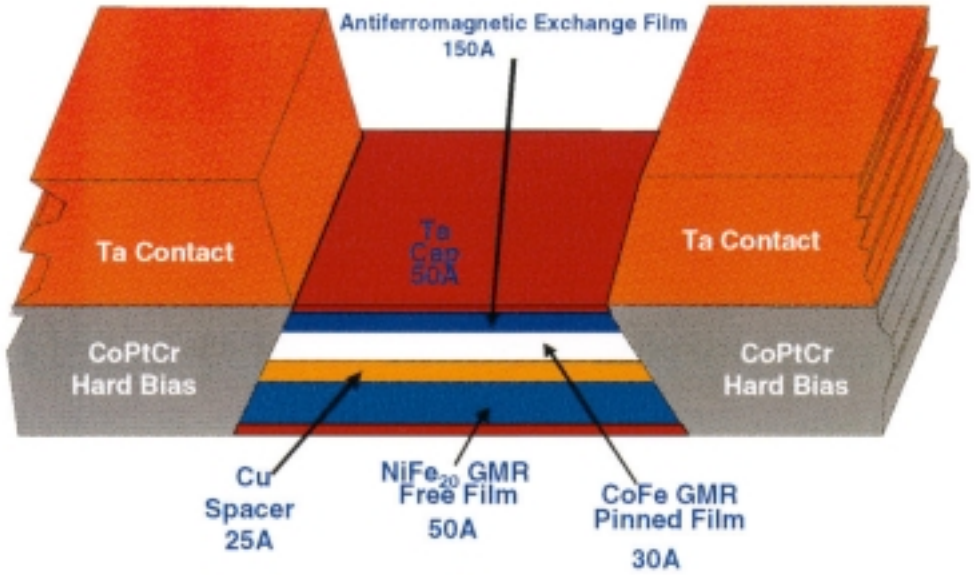
GMR-READ.CDR

IBM

IBM Advanced Technology

GMR Read Head Structure

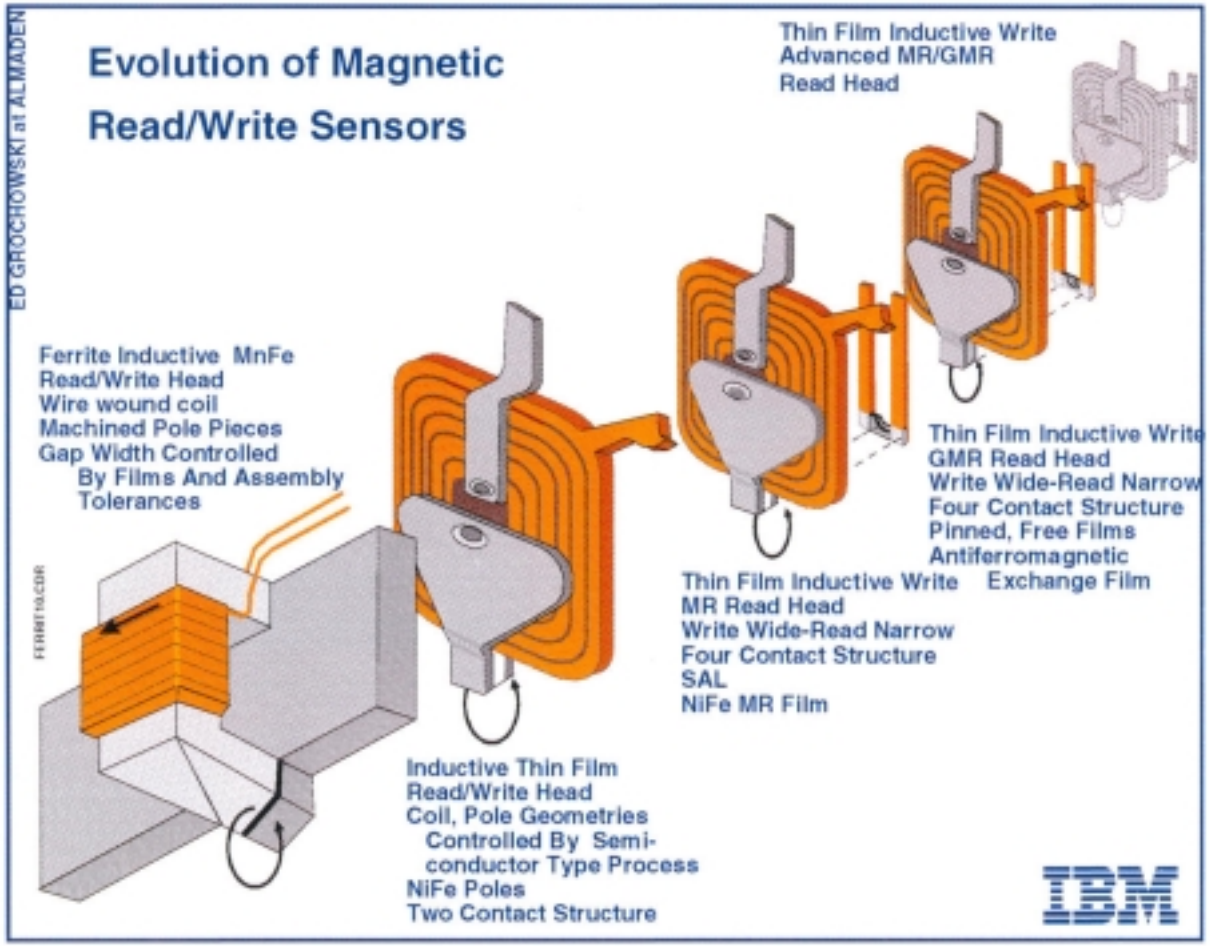
Spin Valve/GMR Sensor

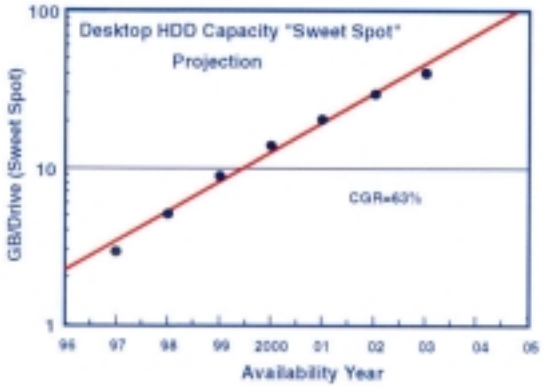


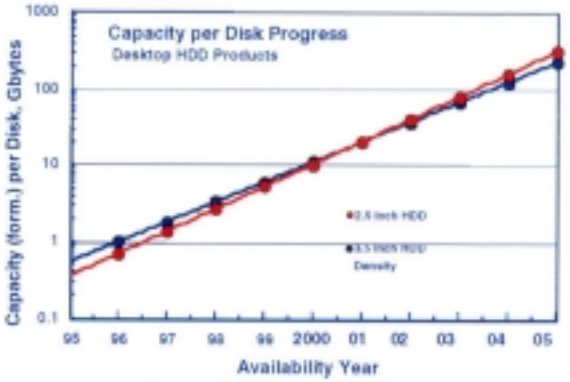
GMR2000A.CDR

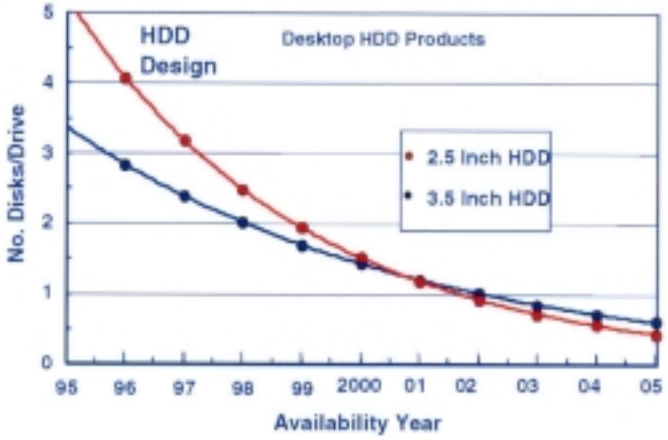
IBM

IBM Advanced Technology


ED GROCHOWSKI at ALMADEN
Evolution of Magnetic
Read/Write Sensors
Thin Film Inductive Write
Advanced MR/GMR
Read Head
Ferrite Inductive MnFe
Read/Write Head
Wire wound coil
Machined Pole Pieces
Gap Width Controlled
By Films And Assembly
Tolerances
Thin Film Inductive Write
GMR Read Head
Write Wide-Read Narrow
Four Contact Structure
Pinned, Free Films
Antiferromagnetic
Exchange Film
Thin Film Inductive Write
MR Read Head
Write Wide-Read Narrow
Four Contact Structure
SAL
NiFe MR Film
Inductive Thin Film
Read/Write Head
Coil, Pole Geometries
Controlled By Semi-
conductor Type Process
NiFe Poles
Two Contact Structure
IBM


Desktop HDD Capacity "Sweet Spot"
Projection
CGR=63%
GB/Drive (Sweet Spot)
100
10
1
96
97
98
99
2000
01
02
03
04
05
Availability Year

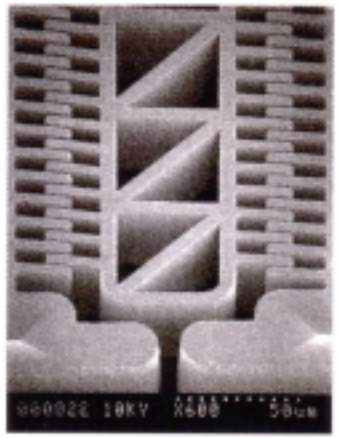

Capacity per Disk Progress
Desktop HDD Products
Capacity (form.) per Disk, Gbytes
1000
100
10
1
0.1
95
96
97
98
99
2000
01
02
03
04
05
Availability Year


HDD
Design
Desktop HDD Products
2.5 Inch HDD
3.5 Inch HDD
No. Disks/Drive
5
4
3
2
1
0
95
96
97
98
99
2000
01
02
03
04
05
Availability Year

IBM

Microactuator for Precision Track Following

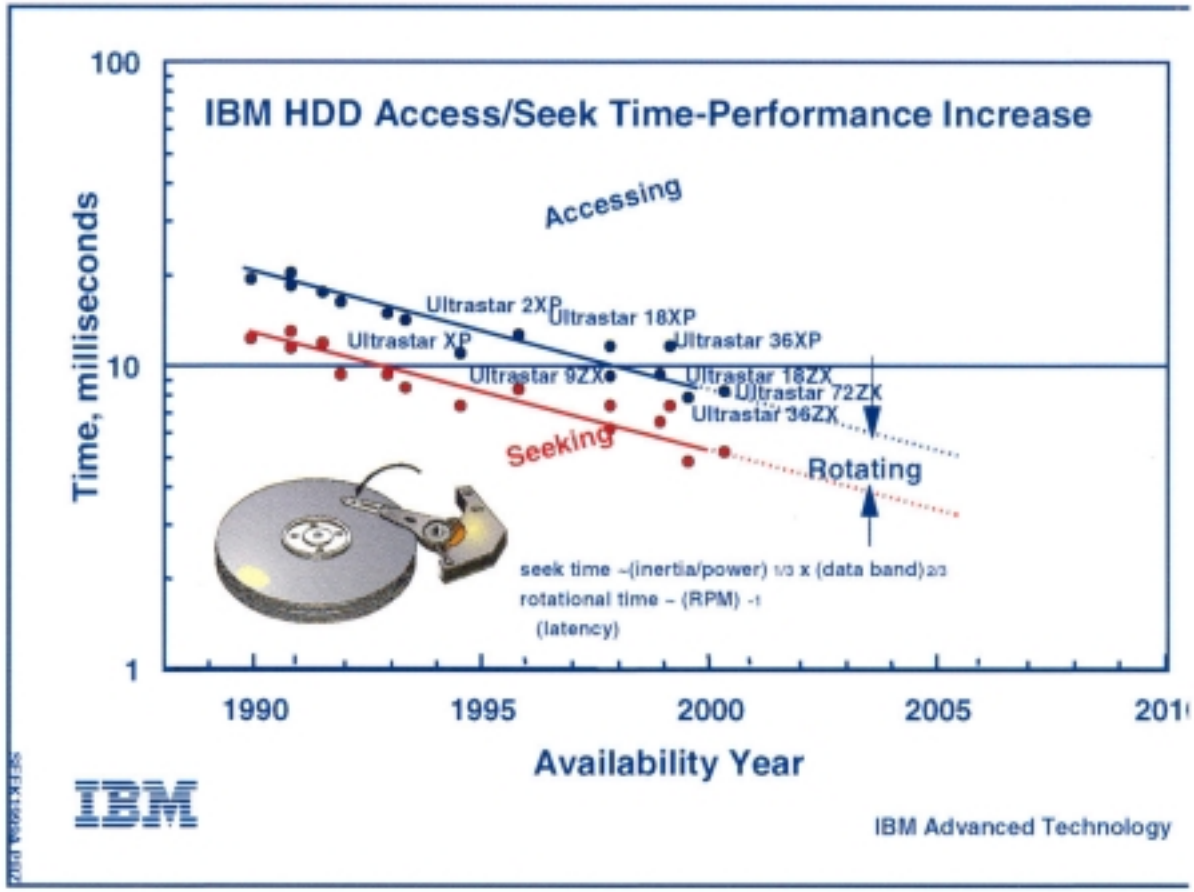
A secondary actuator between the suspension and slider can provide precise head positioning over the data track. Motion of the head results when voltage is applied to this actuator.



A MEMS (micromachined electromechanical systems) microactuator device fabricated using semiconductor processes with a four μm thickness over a 40 μm height.

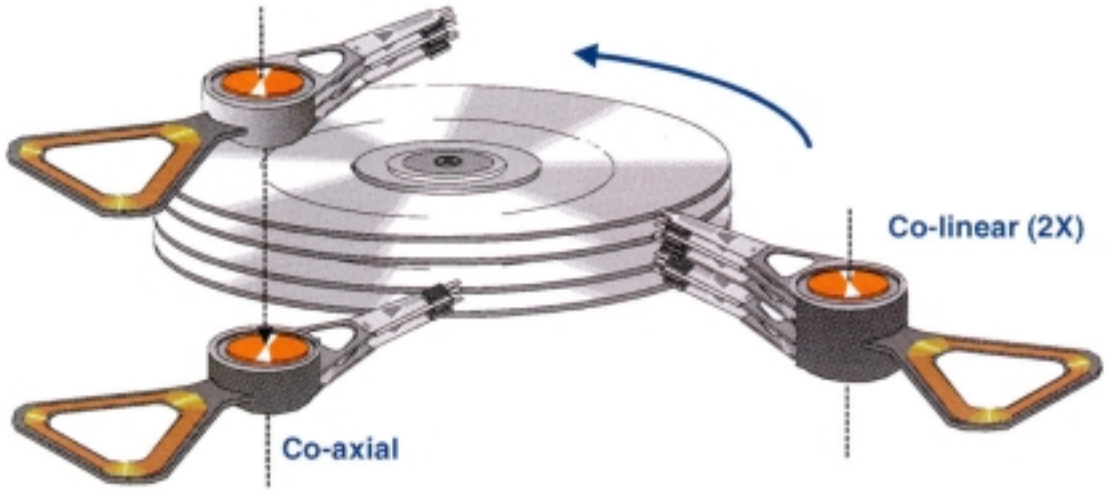
IBM

IBM Advanced Technology


IBM HDD Access/Seek Time-Performance Increase
Accessing
Seeking
Rotating
Ultrastar 2XP
Ultrastar 18XP
Ultrastar XP
Ultrastar 36XP
Ultrastar 9ZX
Ultrastar 18ZX
Ultrastar 72ZX
Ultrastar 36ZX
seek time ~(inertia/power) 1/3 x (data band)2/3
rotational time ~ (RPM) -1
(latency)
Time, milliseconds
100
10
1
1990
1995
2000
2005
Availability Year
IBM
IBM Advanced Technology

ED GROCHOWSKI at ALMADEN

Dual Actuator Technology



Advantages

Significant reduction in seek and latency times, access time

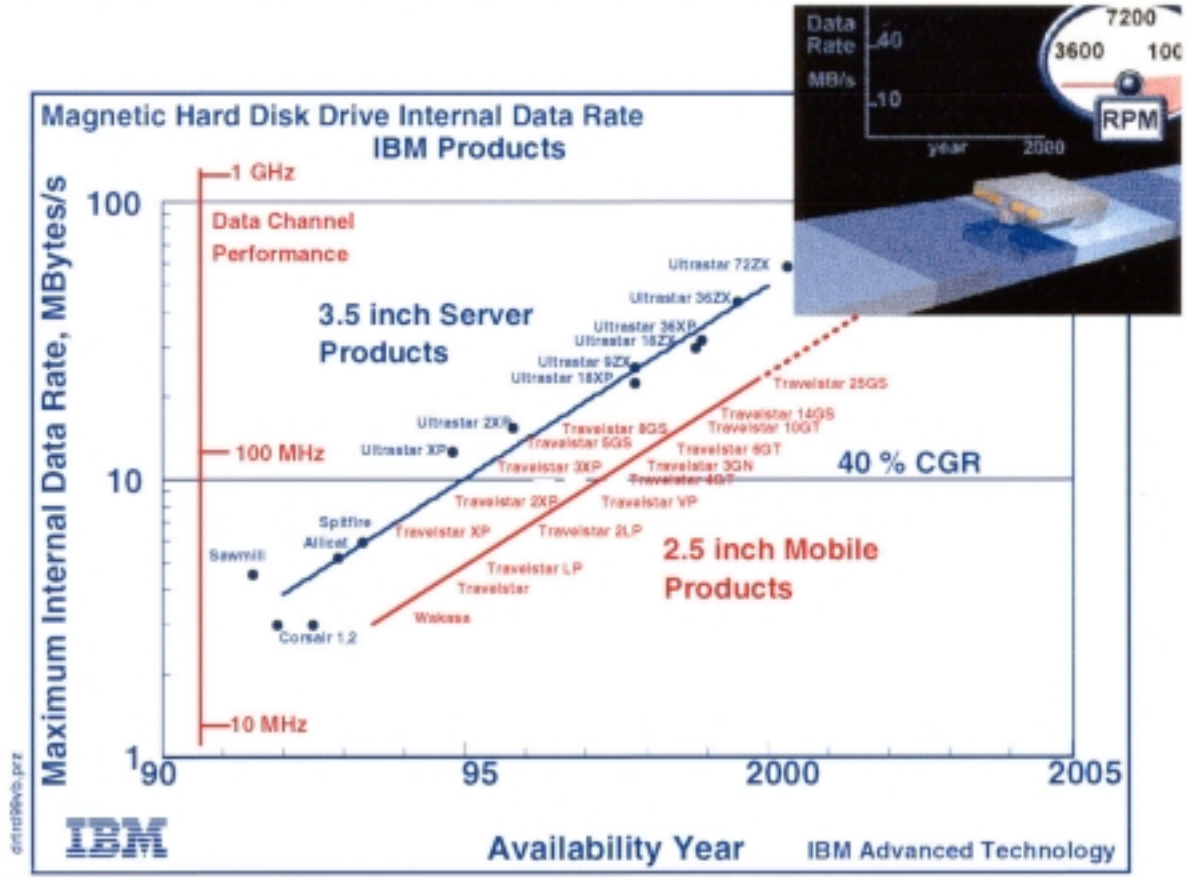
Disadvantages

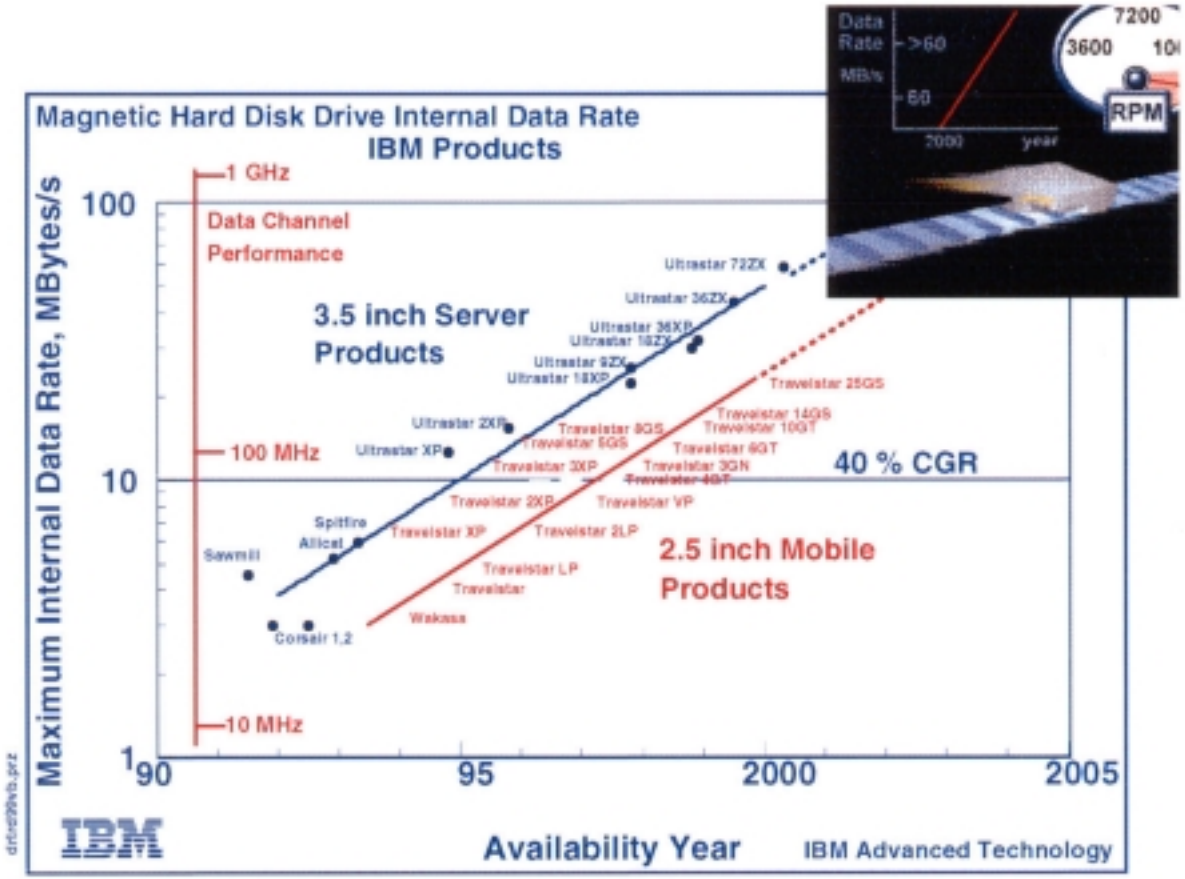
2X Actuator motors
2X Heads, suspensions, arms (co-linear)
2X Key electronic components
Space, power constraints
Cost increase

DISKTECHNIAL.COM

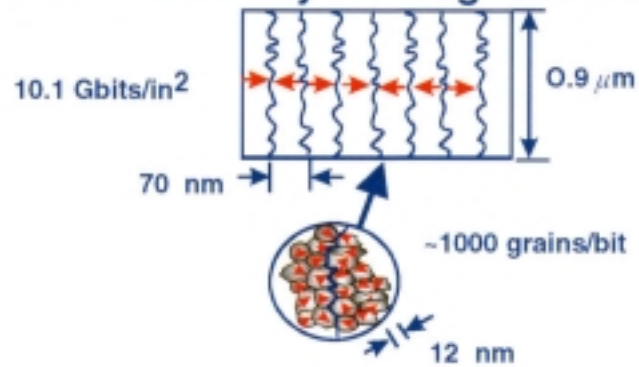
IBM

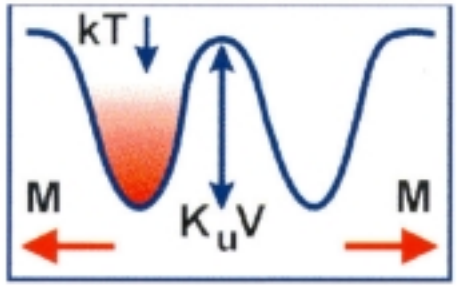
IBM Advanced Technology


Magnetic Hard Disk Drive Internal Data Rate
IBM Products
Maximum Internal Data Rate, MBytes/s
100
10
1
90
95
2000
2005
Availability Year
1 GHz
Data Channel
Performance
100 MHz
10 MHz
3.5 inch Server
Products
2.5 inch Mobile
Products
40 % CGR
Ultrastar 72ZX
Ultrastar 36ZX
Ultrastar 36XP
Ultrastar 18ZX
Ultrastar 9ZX
Ultrastar 18XP
Ultrastar 2XP
Ultrastar XP
Spitfire
Allicat
Sawmill
Corsair 1,2
Travelstar 25GS
Travelstar 14GS
Travelstar 10GT
Travelstar 8GS
Travelstar 5GS
Travelstar 6GT
Travelstar 3GN
Travelstar 3XP
Travelstar 2XP
Travelstar VP
Travelstar XP
Travelstar 2LP
Travelstar LP
Travelstar
Wakasa
IBM
IBM Advanced Technology
Data
Rate
MB/s
40
10
year
2000
7200
3600
RPM


Magnetic Hard Disk Drive Internal Data Rate
IBM Products
Maximum Internal Data Rate, MBytes/s
100
10
1
1 GHz
Data Channel
Performance
100 MHz
10 MHz
3.5 inch Server
Products
2.5 inch Mobile
Products
40 % CGR
Ultrastar 72ZX
Ultrastar 36ZX
Ultrastar 36XP
Ultrastar 18ZX
Ultrastar 9ZX
Ultrastar 18XP
Ultrastar 2XP
Ultrastar XP
Spitfire
Allical
Sawmill
Corsair 1,2
Travelstar 25GS
Travelstar 14GS
Travelstar 10GT
Travelstar 9GS
Travelstar 5GS
Travelstar 6GT
Travelstar 3XP
Travelstar 3GN
Travelstar 40GT
Travelstar 2XP
Travelstar VP
Travelstar 3P
Travelstar 2LP
Travelstar LP
Travelstar
Wakasa
90
95
2000
2005
Availability Year
IBM Advanced Technology
IBM
Data
Rate
MB/s
>60
60
2000
year
7200
3600
RPM

Thermal Stability for Magnetic Recording



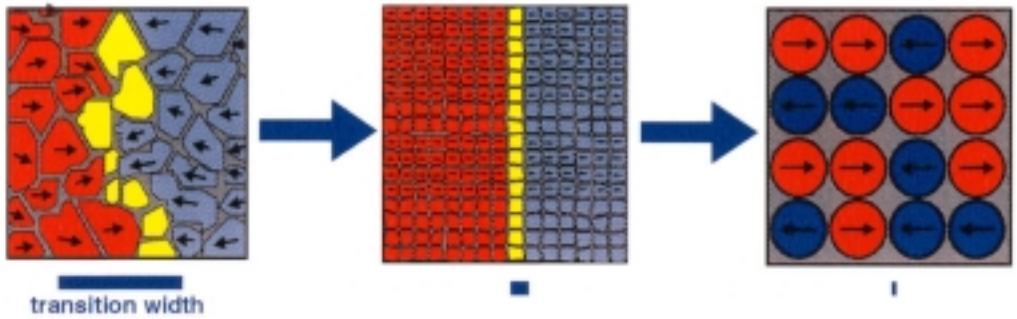


$$\tau = \tau_0 e^{\frac{K_u V}{kT}}$$

IBM

IBM Advanced Technology

The Perfect Magnetic Medium



TODAY

- large random grains
- broad noisy transitions
- thermally stable

NEAR FUTURE

- small uniform grains
- sharper transitions
- less thermally stable

FUTURE

- patterned single bits-ultimate single grain/bit
- sharper transitions
- thermally stable

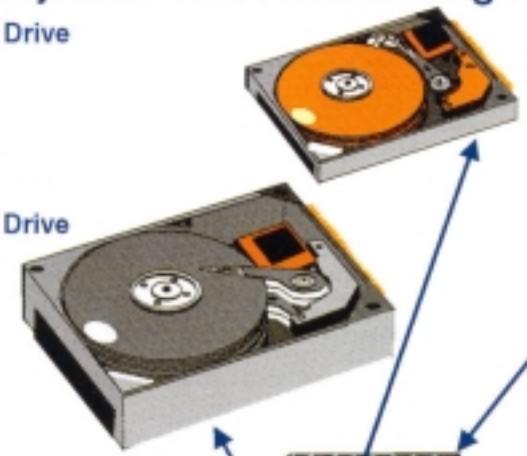
IBM

IBM Advanced Technology

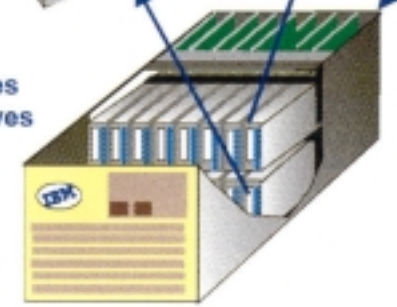
Projected Year 200X Storage Array System

36 Gbyte Disk Drive
2.5 Inch
15K RPM
Dual Actuator
Access 3ms

72 Gbyte Disk Drive
3.25 Inch
10K RPM
Access 7 ms



Per Drawer
8 – 36 GB 2.5 Inch Drives
8 – 72 GB 3.25 Inch Drives
0.6 TB RAID 5

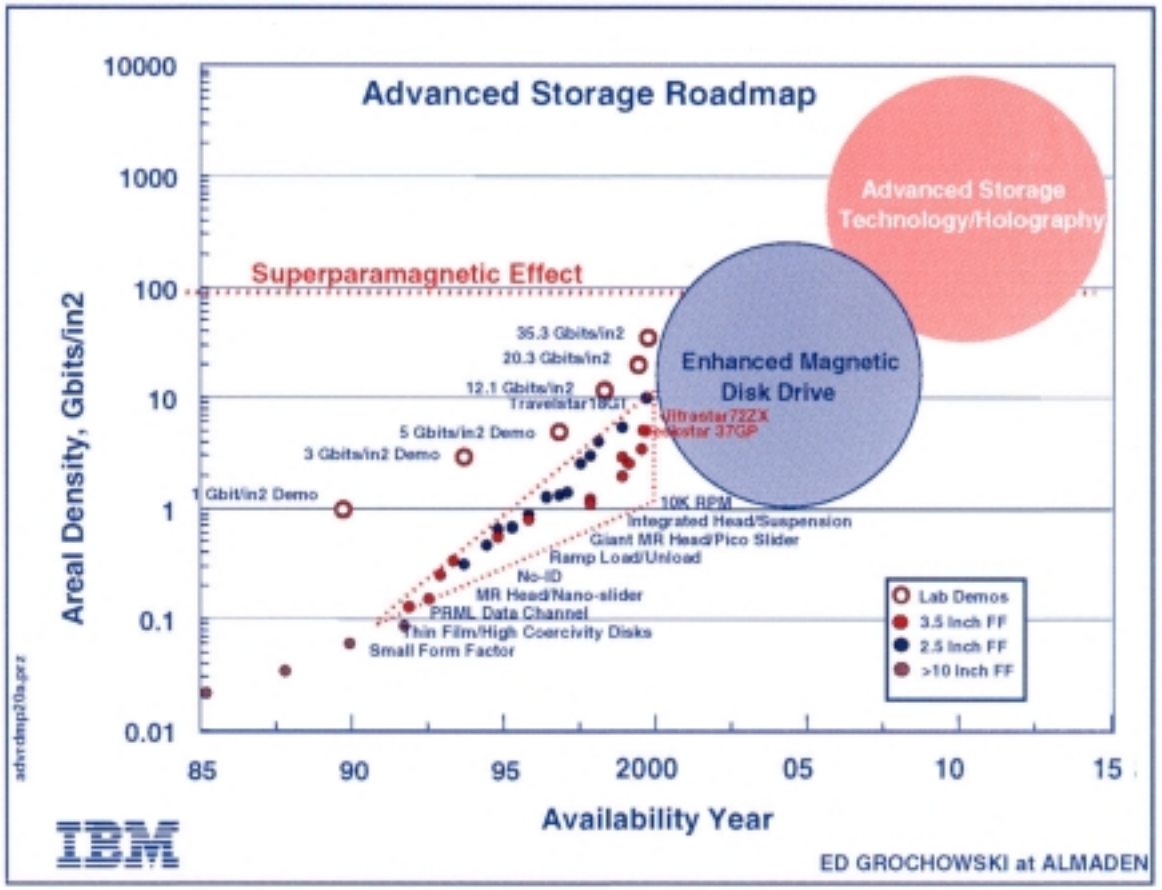


- >6TB – RAID 5
- 80 – 36 GB 2.5 Inch Drives
- 80 – 72 GB 3.25 Inch Drives
- 3+P Fault Tolerance Array
- 4 Arrays per Drawer
- Integrated Tape/DVD Libraries

RAMAC17.CDR

IBM

IBM Advanced Technology


Advanced Storage Roadmap
Advanced Storage Technology/Holography
Superparamagnetic Effect
Enhanced Magnetic Disk Drive
Areal Density, Gbits/in2
10000
1000
100
10
1
0.1
0.01
35.3 Gbits/in2
20.3 Gbits/in2
12.1 Gbits/in2
Travelstar18GT
Ultrastar72ZX
Deskstar 37GP
5 Gbits/in2 Demo
3 Gbits/in2 Demo
1 Gbit/in2 Demo
10K RPM
Integrated Head/Suspension
Giant MR Head/Pico Slider
Ramp Load/Unload
No-ID
MR Head/Nano-slider
PRML Data Channel
Thin Film/High Coercivity Disks
Small Form Factor
Lab Demos
3.5 Inch FF
2.5 Inch FF
>10 Inch FF
85
90
95
2000
05
10
15
Availability Year
advrdmp20a.prz
IBM
ED GROCHOWSKI at ALMADEN

Conclusions/Summary

- 43 Years Of HDD Innovations Have Greatly Expanded Capacity and Performance, Reduced Price And Increased Applications
- Currrent HDD Products Have Achieved >10 Gbits/in^2
- Magnetic Heads Have Been Demonstrated At >35 Gbits/in^2 In Lab
- GMR Technology Should Sustain Areal Densities >60 Gbits/in^2
- Lower Head/Disk Spacings (<15 nm) Require Super Smooth Disks, Ramp Load/Unload, Glass Substrates
- Disk Drive Enhancements Are Required, MEMS, Dual Actuators
- Challenges of Superparamagnetism Will Be Addressed
- Magnetic Products Will Continue To Dominate Storage Industry Well Into The Next Millenium

IBM